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HIDDEN SECTOR OF SUPERSTRING MODELS:
an effective lagrangian analysis

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ABSTRACT

The effective lagrangian for the strongly interacting E_8-sector of the superstring-type supergravity models is constructed. Dynamical supersymmetry breaking and other nonperturbative effects are analysed.

All phenomenological applications of supergravity models [1] existing so far require the existence of a so-called hidden sector. The role of the hidden sector, usually composed of one or more scalar supermultiplets, is to break supersymmetry and contribute to the cancellation of the cosmological constant.

Recently a new heterotic superstring theory has been formulated [2] and studied in much detail. The supergravity models emerging from the compactification [3] of the heterotic string theory have a remarkable $E_6 \times E_8$ gauge group structure. E_6 is considered to be the grand unifying group; quarks and leptons transform as $\underline{27}$ under E_6 and singlets under E_8. Since the E_8-interacting sector communicates with the rest of the world via gravitational forces exclusively, it is natural to consider it as a candidate for the hidden sector of the effective supergravity theory. Its massless spectrum consists of gauge bosons and gauginos, therefore one might expect that a composite object takes over the role of the traditional scalar multiplet. It is worth mentioning that the idea that nonperturbative effects, in particular fermion condensations, are important in supergravity theories, breaking supersymmetry or contributing to the cancellation of the cosmological constant, has been around for some time [4,5,6]. So far it is only the heterotic string theory, which contains an intrinsic E_8 gauge force capable of producing all sorts of nonperturbative phenomena. The purpose of the present letter is to analyse those effects from the effective lagrangian point of view.

The problem of constructing an effective lagrangian for the supersymmetric Yang-Mills theory coupled to supergravity looks more complicated than in the case of global supersymmetry [7]. The basic difference is that in the global case the coupling constant is fixed, whereas in the superstring models it has to be determined dynamically as the vacuum expectation value of a dilaton field. The part of the superstring-type supergravity lagrangian [8,9] involving the E_8 gauge fields A_μ is

$$\begin{aligned}\mathscr{L}_{gauge} = \; & -\tfrac{1}{4}\phi^{-\frac{3}{4}} e^{3\sigma} \mathrm{Tr}\left(F_{\mu\nu}F^{\mu\nu}\right) \\ & + \tfrac{3}{4}\sqrt{2}\phi^{-\frac{3}{2}} e^{6\sigma} h_{\mu\nu\rho} \mathrm{Tr}\left(A^{[\mu}F^{\nu\rho]} - \tfrac{2}{3}A^{[\mu}A^{\nu}A^{\rho]}\right) \\ & + (\text{ terms of higher order in Newton's constant } G), \qquad (1)\end{aligned}$$

where ϕ and σ are real scalar fields emerging from the supergravity multiplet and the dilatation mode of the extra six dimensions, respectively. $h_{\mu\nu\rho}$ denotes the field strength of the antisymmetric two-index component of the supergravity multiplet. Define now a pseudoscalar D by a duality [9] transformation:

$$\phi^{-\frac{3}{2}} e^{6\sigma} h_{\mu\nu\rho} = \varepsilon_{\mu\nu\rho\lambda} \partial^\lambda D \qquad (2)$$

and introduce a scalar superfield S:

$$S = e^{3\sigma}\phi^{-\frac{3}{4}} + 3i\sqrt{2}D + \ldots \qquad (3)$$

After integration by parts the lagrangian $\mathscr{L}_{gauge}$ can be viewed as a part of a globally supersymmetric lagrangian

$$\mathscr{L} = \tfrac{1}{4}[SWW]_F + \text{h.c.}, \tag{4}$$

where W denotes the usual gauge-field strength superfield [10].

Consider for a moment the limit $G = M_{Pl}^{-2} \to 0$. In this limit S becomes a gauge singlet, with the vacuum expectation value of its scalar component equal to the inverse square of the coupling constant. When this coupling constant is large, nonperturbative phenomena, like the formation of bound states, become important. The description of our model in terms of gauge bosons and gauginos is inadequate in this regime, therefore one has to construct an effective lagrangian for the interactions of composite states. Such a construction has been already given in [7]. The lightest composite multiplet is assumed to be the gauge singlet $U = WW$. It contains the gaugino composite $\lambda\lambda$ as its scalar component. The effective lagrangian contains the "anomalous" part

$$\mathscr{L}_{\text{anom}} = \frac{\beta_0}{96\pi^2}\left[U\cdot\log\left(\mu^{-3}U\cdot e^{\frac{24\pi^2 S}{\beta_0}}\right)\right]_F + \text{h.c.}$$

$$= \tfrac{1}{4}[US]_F + \frac{\beta_0}{96\pi^2}\left[U\cdot\log\left(\mu^{-3}U\right)\right]_F + \text{h.c.}, \tag{5}$$

which reflects the presence of the supermultiplet structure of trace, axial and superconformal anomalies, in the one-loop approximation. β_0 denotes the one-loop coefficient of the beta function ($\beta_0 = 90$ for the gauge group E_8). The mass parameter μ corresponds to the renormalization scale.

The next step is to consider $\mu \ll M_{Pl}$ and couple our effective theory back to supergravity. The effective superpotential under consideration is

$$f = \tfrac{1}{4}US + \frac{\beta_0}{96\pi^2} U \cdot \log\left(\mu^{-3}U\right) + c\mu^3, \tag{6}$$

where c is an unknown constant which could be in principle determined by studying nonperturbative dynamics in presence of gravity. As we will see later, varying c probes the ability of nonperturbative dynamics to cancel the cosmological constant. In order for S to remain gauge singlet in presence of gravity one has to redefine its pseudoscalar component by adding a Chern-Simons term [8] to $h_{\mu\nu\rho}$ in Eq.(2). It remains now to specify the Kähler potential d. Dimensional reasons [7] and explicit calculations [9] dictate

$$d = \frac{9}{\gamma}\left(U^*U\right)^{\frac{1}{3}} - \frac{1}{8\pi G}\log\left(S+S^*\right), \tag{7}$$

where γ is an unknown constant which will turn out to be irrelevant in further considerations.

The superpotential f together with the Kähler form d, Eqs. (6) and (7), fully specify the interactions of the composite field U and the dilaton S. The effective potential [11] is given by

$$V = e^{8\pi Gd}\left[\sum_{Z=U,S}\left(\frac{\partial^2 d}{\partial Z\partial Z^*}\right)^{-1} \left| \frac{\partial f}{\partial Z} + 8\pi G\frac{\partial d}{\partial Z} f \right|^2 - 24\pi G|f|^2 \right]. \tag{8}$$

Numerical minimalization of the above potential yields the following results. A zero-value minimum exists at

$$S \simeq 0.522\beta \ , \quad U \simeq [0.254]^{\beta}\cdot\mu^{3}/e \ ; \quad \beta := \beta_0/90$$

for the value of the parameter $c \simeq -0.26$. Hence our model predicts the gaugino condensation $\langle\lambda\lambda\rangle$ at the scale μ corresponding to the coupling constant $\alpha(\mu) \simeq 0.15/\beta$. This is a rather amusing result which agrees well with the intuitive understanding of fermion condensations [12] as due to attractive gauge forces. Our main result is that supersymmetry gets spontaneously broken; the gravitino acquires a mass of order $G\mu^3$. This is consistent with the direct inspection of the gravitino supersymmetry transformations [5,6], which shows that the gaugino condensation breaks supersymmetry in the superstring-type supergravity models. The fact that the value of the potential at the minimum can be tuned to zero by an appropriate choice of the constant c proves that nonperturbative effects are able to contribute to the cancellation of the cosmological constant.

The scale μ of supersymmetry breaking is going to be determined by the boundary condition: at the Planck scale the E_8 coupling constant should be equal to the grand-unifying E_6 coupling constant [13]. One would like to have $\mu \sim 10^{10} - 10^{13}$GeV, so that the gravitino mass is of the order of the weak scale. Such a value of μ is however incompatible with the gauge group E_8 being unbroken. The coupling constant of E_8 runs very fast, decreasing from 0.15 at 10^{13}GeV to a typical value lower than 0.005 at 10^{17}GeV, which is definitely low for a grand-unifying coupling constant. Therefore phenomenological constraints seem to require that the group E_8 breaks in the compactification process to a smaller group with $\beta < 1$. This allows the coupling constant to be larger at the supersymmetry breaking scale and to decrease more slowly towards the Planck scale.

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